Central U.S. Earthquake Consortium (CUSEC) State Geologists' Procedures for New Madrid Catastrophic Planning Initiative Phase II 8-State Soil Site Class, Liquefaction Susceptibility, and Soil Response Maps

CUSEC Association of the State Geologists (2008)

The CUSEC State Geologists produced a regional Soil Site Class map (NEHRP Soil Profile Type Map), a Liquefaction Susceptibility Map and a Soil Response Map for the 8 states to be used in the FEMA New Madrid Catastrophic Planning Initiative Phase II work. The USGS Geologic Investigation Series I-2789 *Map of Surficial Deposits and Materials in the Eastern and Central United State* (East of 102 degrees West Longitude) by David S. Fullerton, Charles A. Bush and Jean N. Pennell (2003) was the base map used for this work. Each State Geological Survey produced its own state map version of the Soil Site Class and Liquefaction Susceptibility maps.

Soil Site Classification Map

The procedures outlined in the NEHRP provisions (Building Seismic Safety Council, 2004) and the 2003 International Building Codes (International Code Council, 2002) were followed to produce the soil site class maps. Procedures start with the simple assignment of areas for *liquefiable* soils, *thick soft clay* and *no* or *thin* soil areas:

Liquefiable - Soil Site Class F Soils: Checked for the four categories of Site Class F. If the site corresponds to any of these categories, classified the site as *Site Class* F.

Categories for *Site Class* F are:

Any profile containing soils having one or more of the following characteristics:

1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.

2. Peats and/or highly organic clays ($H > 10$ feet of peat and/or highly organic clays where H = thickness of soil)

3. Very high plasticity clays ($H > 25$ feet with plasticity index $PI > 75$)

4. Very thick soft/medium stiff clay ($H > 120$ feet)

Note: All but the Kentucky Geological Survey mapped F soils.

Thick Soft Soils: Checked for the existence of a total thickness of soft clay > 10 ft (3 m) where a soft clay layer is defined by $w \geq 40$ percent and $PL > 20$. If these criteria were satisfied, classified the site as *Site Class* E.

Thin Soils International Building Codes exclude soils less than 10 feet thick between the top of bedrock and building foundations for consideration in the soil site class maps. Therefore, if maps exist showing thickness of surficial materials, another area of the state can be eliminated for further consideration and classified according to the bedrock properties.

Typically soil site class maps are produced using "local" site conditions based on the average shear wave velocity of the upper **30 meters** of the "local" site geology. CUSEC State Geologists **used the entire column** of soils material down to bedrock and **did not** include any bedrock in the calculation of the average shear wave velocity for the column, since it is the soil column and the difference in shear wave velocity of the soils in comparison to the bedrock which influences much of the amplification. Using these procedures along with the Fullerton et al., (2003) map a Soil Site Class Map was produced for eight states (figure 1).

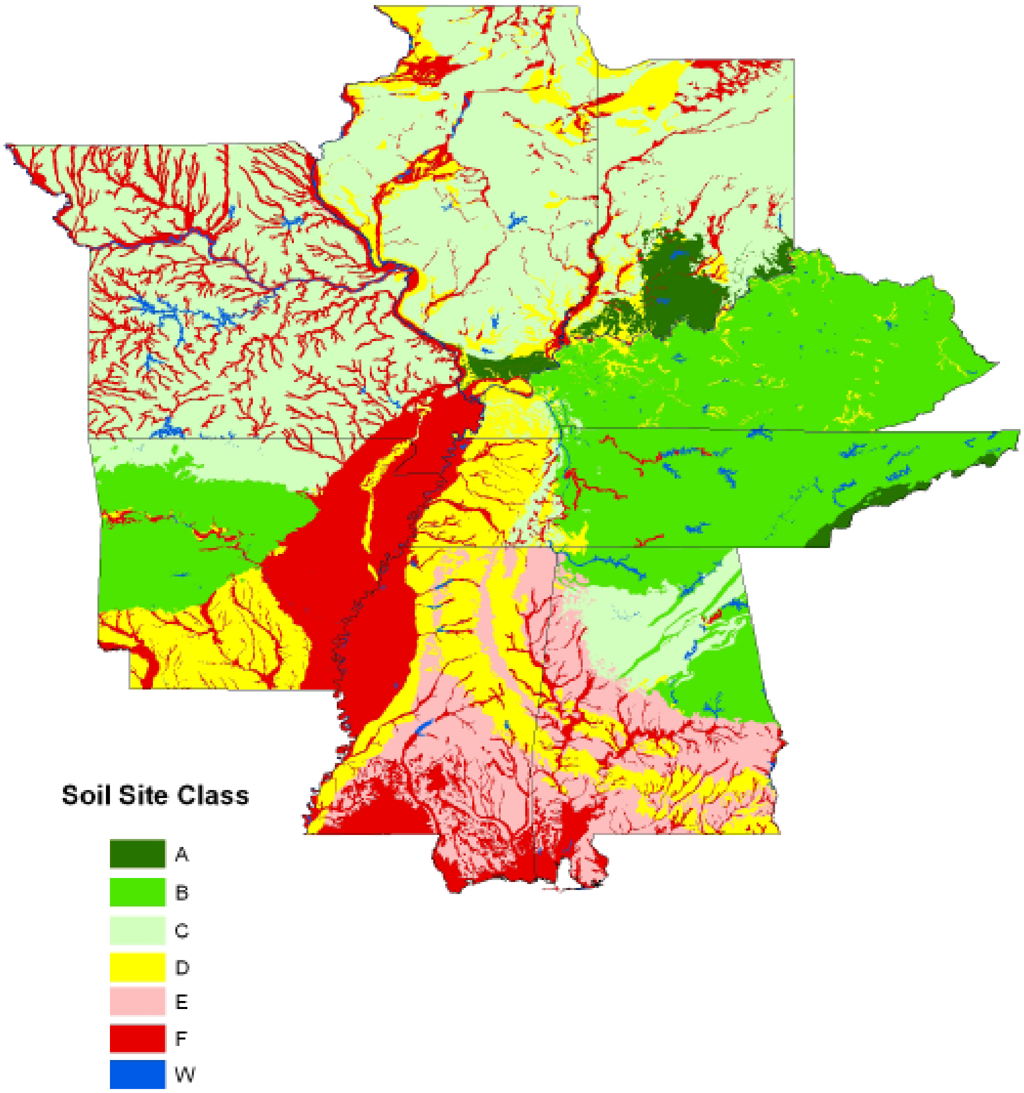

Figure 1. Soil Site Class Map produced by the CUSEC State Geologists using Fullerton et al., (2003) map as a base and shear wave velocity data of soils in the Central U.S.

Liquefaction Susceptibility Map

For HAZUS, the liquefaction susceptibility is based on the Youd and Perkins (1978) paper and table 4.10 below from the HAZUS Manual (table 1). It was matched with the Fullerton et al., (2003) map and additional interpretations of the state geological survey staff to produce the eight states Liquefaction Susceptibility Map (figure 2).

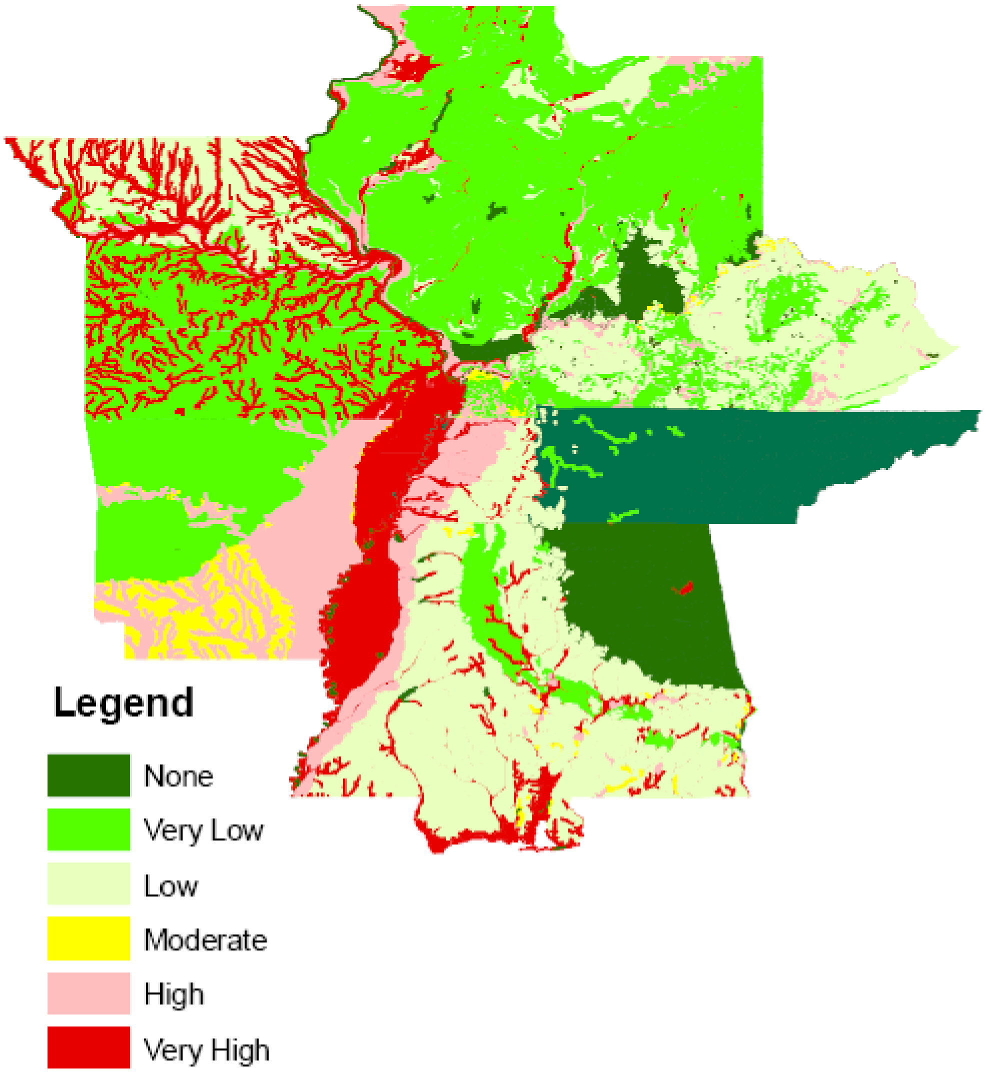

Figure 2. Liquefaction Susceptibility Map produced by the CUSEC State Geologists using the Fullerton et al., (2003) geologic base map and Youd and Perkins (1978) classification.

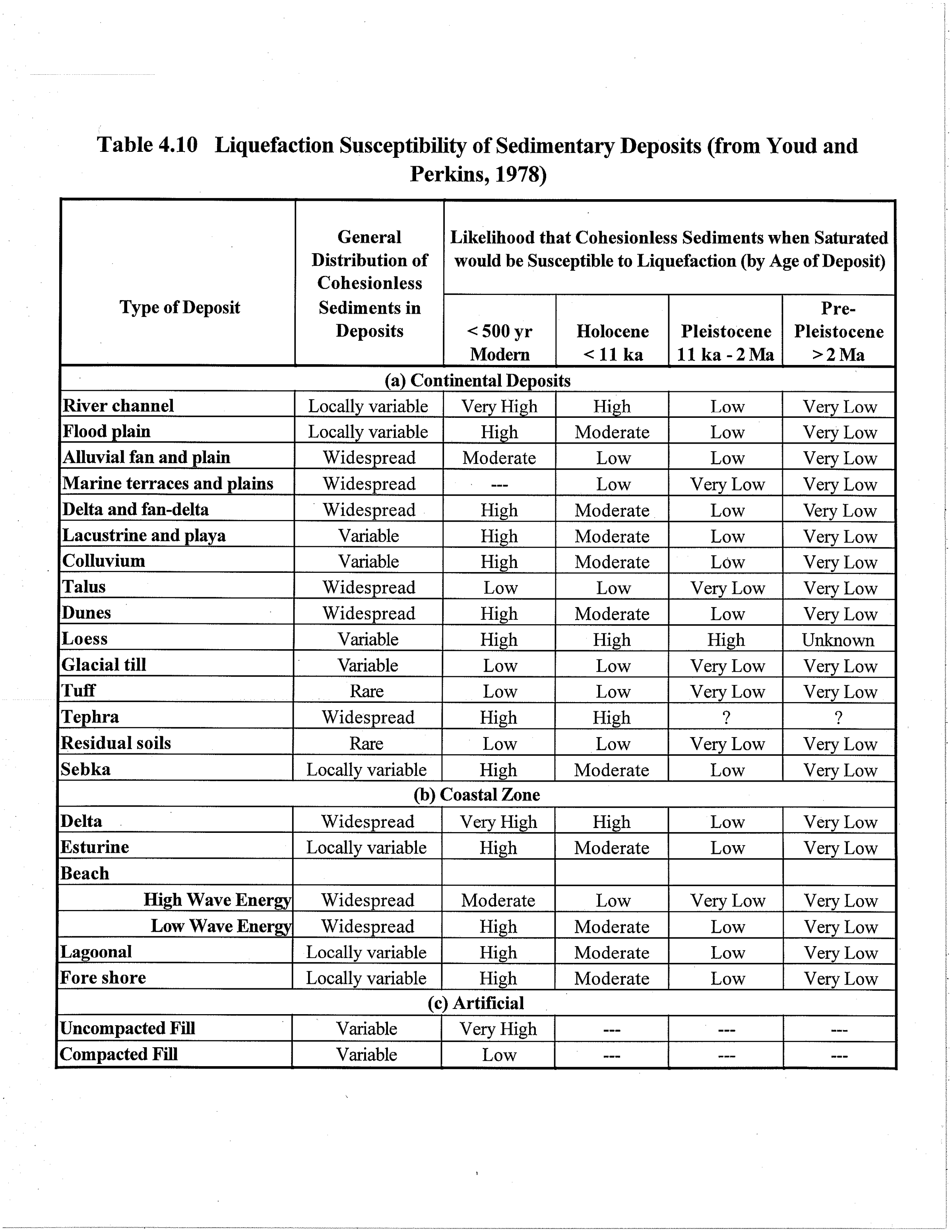

Table 4.10 Liquefaction Susceptibility of Sedimentary Deposits (from Youd and Perkins, 1978)

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments when Saturated would be Susceptible to Liquefaction (by Age of Deposit)			
		< 500 yr Modern	Holocene < 11 ka	Pleistocene 11 ka - 2 Ma	Pre-Pleistocene > 2 Ma
(a) Continental Deposits					
River channel	Locally variable	Very High	High	Low	Very Low
Flood plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread	---	Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High	High	Low	Very Low
Esturine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Moderate	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	---	---	---
Compacted Fill	Variable	Low	---	---	---

Table 1. Liquefaction susceptibility classification as presented by Youd and Perkins (1978) and table 4.10 in the HAZUS Manual.

Soil Response Map

The Central U.S. Earthquake Consortium (CUSEC) State Geologists originally produced a Soil Site Classification Map for the eight CUSEC states as outline above. The HAZUS computer program uses the Soil Site Class Map along with an earthquake magnitude and location to calculate the surface ground motions based on amplifications assigned to each soil site class. But the HAZUS program does not perform the analysis outside of 200 km from the earthquake source. To overcome this limitation one needs to produce a ground motion map for the area to be analyzed based on the scenario earthquake event(s) and incorporate it into the HAZUS program.

The project team decided that the ground motion map would be produced by Dr. Chris Cramer of the University of Memphis (previously of USGS) using the methodology outlined in Cramer (2006). The Cramer (2006) methodology used earthquake events on all three segments of the New Madrid faults along with ground motions modified by soil site amplification based on a "soil response map" and reference shear wave velocity profiles for each soil type. Cramer (2006) used the method of Toro and Silva (2001) which produced a soil response map (figure 3) and the Soller and Packard (1998) national scale map of Quaternary (glacial materials) characteristics and thicknesses and embayment/Memphis area reference shear wave velocity profiles to generate soil amplification values at grid points. The amplification distribution per grid point was calculated with intense computer computation for various input parameters using Shake91. In 2006, Dr. Cramer used this method and resources in order to have the same representation of materials and thicknesses across the 8 states and not a patch work of soil related maps of different characteristics from each state.

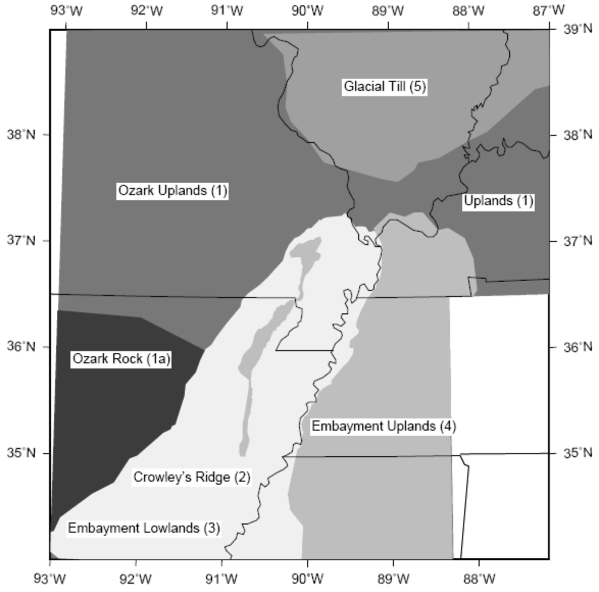

Figure 3. Toro and Silva (2001) soil response map and soil types.

Phase II project constraints required that the complete eight state soil response map be produced within two months. The Phase II Earthquake Scenario Subcommittee decided that for the eight state analyses a simple approach would be to have all three fault segments going off "at once" as in the Cramer (2006) analysis. It was pointed out that this approach would produce a lower loss estimate than if each of the three segments go off individually in succession since partially damaged structures from one event could be greatly affected by the second and third events. But, the estimated impact from such an occurrence can not be modeled without an impossible task of changing the fragility characteristics of the damaged inventory after each event and then running the next event! For the Phase II project, the 7.7 magnitude earthquake events were associated with the *Southwest segment*, *Reelfoot thrust segment* and the *Northeast segment* of the New Madrid seismic zone defined by the decades of recorded seismic activity.

The short time frame required a simple new soil response map covering the entire eight states and continued use by Dr. Cramer of shear wave velocity profiles defined in Toro and Silva (2001) and used in Dr. Cramer's previous ground motion map production (2006). These profiles with detailed information of dynamic properties, density, etc. were ready for use in the Shake91 analysis by Dr. Cramer. The Toro and Silva (2001) profiles are defined as Lowlands, Uplands, and Glacial Till. The Toro profiles were matched to the shear wave reference profiles previously used for the soil site classification mapping of the CUSEC State Geologists and a new eight state soil response map was produced with provinces defined by the Toro and Silva (2001) shear wave reference profiles of Lowlands, Uplands and Glacial Till (figure 4).

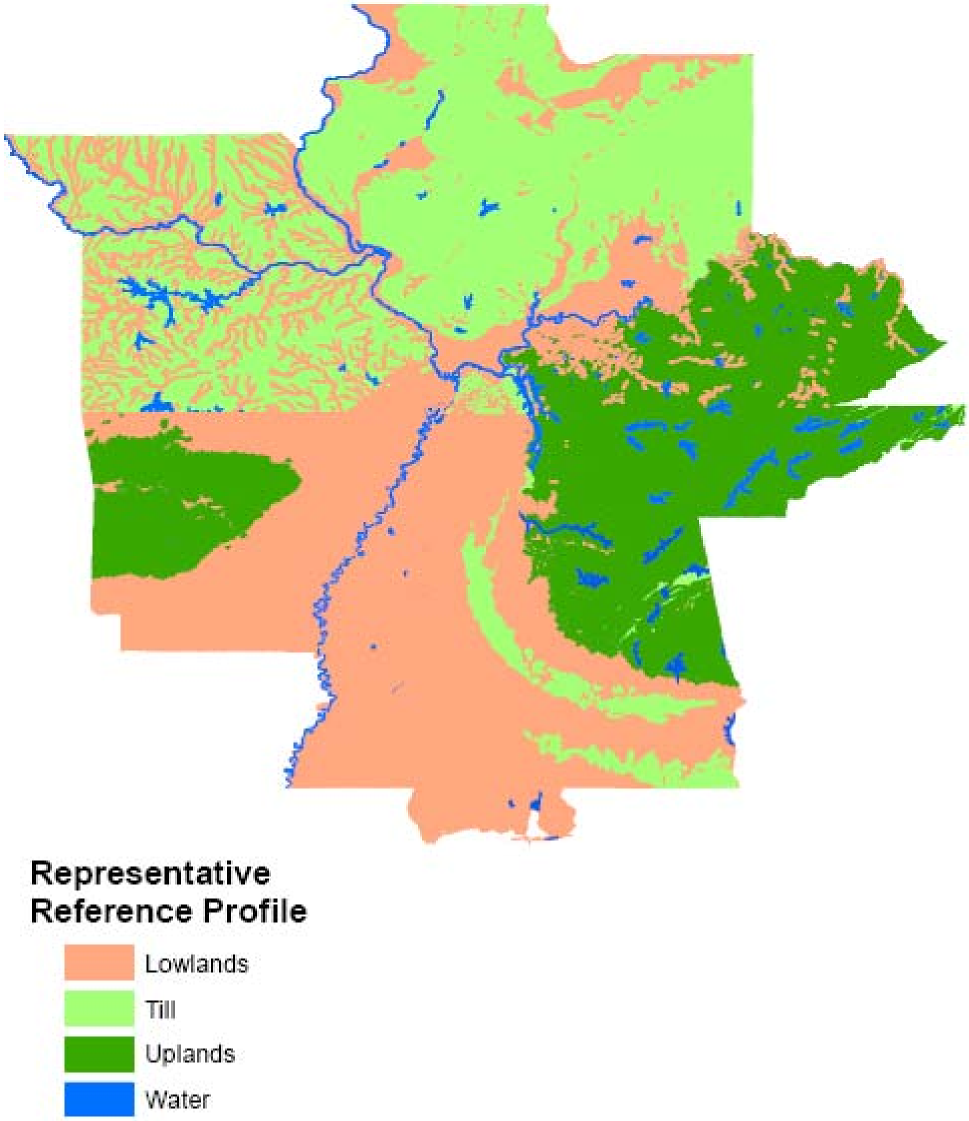

Figure 4. Eight state soil response map produced with provinces defined by the Toro and Silva (2001) shear wave reference profiles of Lowlands, Uplands and Glacial Till.

The new soil response map adds more detail than the Toro and Silva map and covers the entire eight states. A comparison between the Toro and Silva (2001) soil response map and the CUSEC State Geologists' soil response map is shown in figure 5.

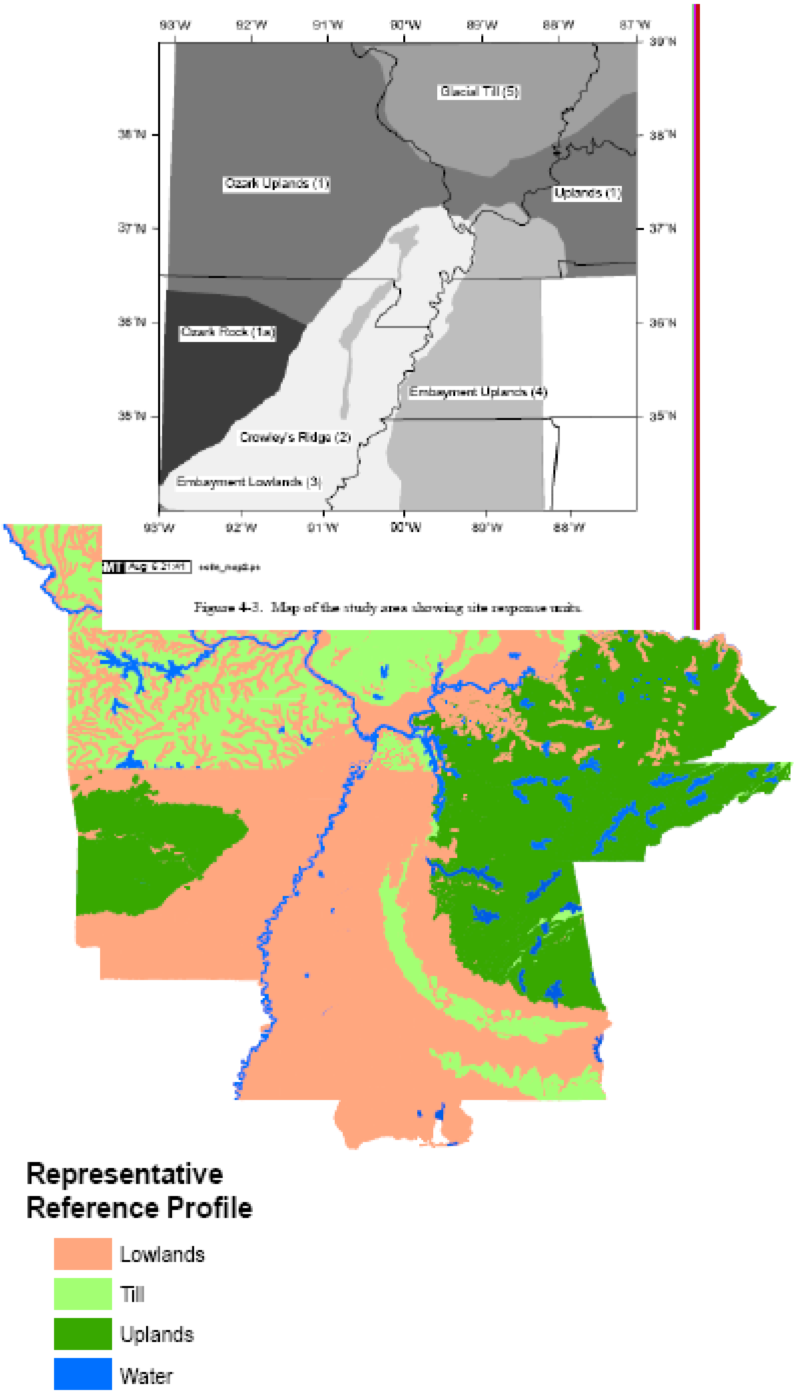

Figure 4-3. Map of the study area showing site response units.

Figure 5. Comparison between soil response maps produced by Toro and Silva (2001) and the CUSEC State Geologists' map for Phase II of the FEMA New Madrid Catastrophic Planning Initiative.

References

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